Assessment of subsidence induced damage to masonry buildings

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Introduction

Evaluating and predicting damage to buildings in subsiding areas is a complex task that requires associating the vulnerability of exposed structures with the intensity of the subsidence hazard.

Damage assessment analyses require detailed information of the features of the exposed buildings (e.g. material of construction, geometry, type of foundation system), and of the subsurface system on which they are resting, which leads to intrinsic uncertainties when dealing with a large number of buildings (Ferlisi et al., 2019, Saeidi et al., 2012).

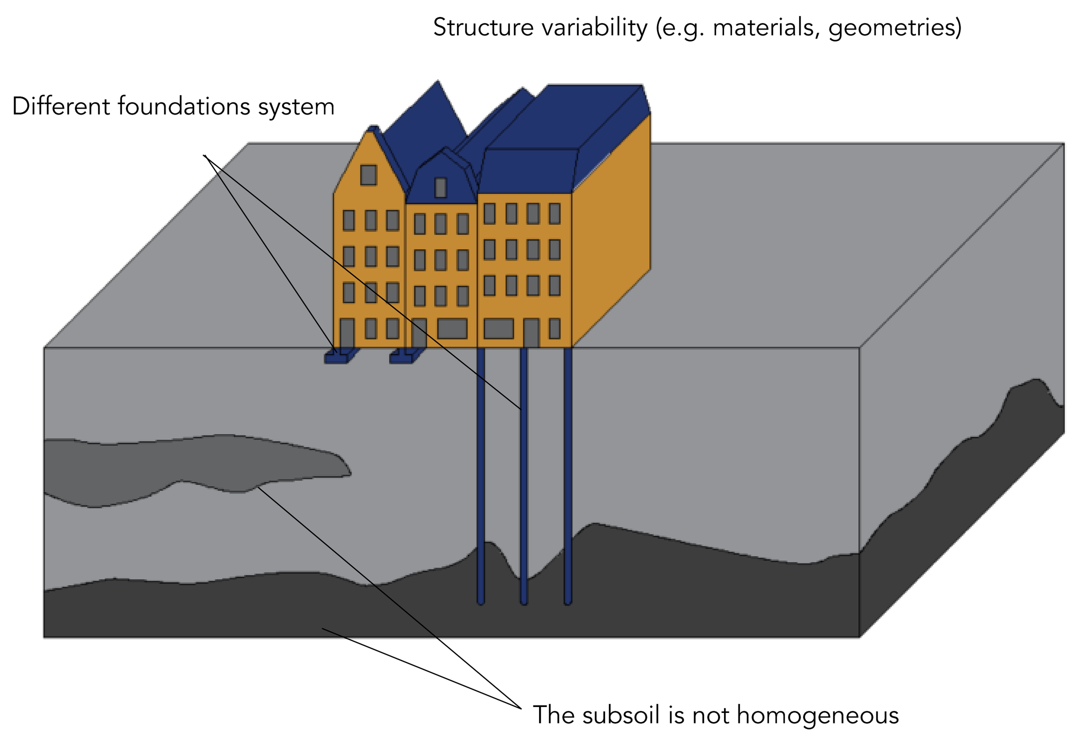

Figure 1. The structure-foundation-soil system: an illustration of the uncertainties and large variability related to the structural and soil features.

Subsidence-damage to buildings

During and just after their construction, structures typically experience settlements which can continue throughout the first few decades (DeJong, 2016) and are not necessarily a symptom of deficiencies.
However, when a structure is unable to accommodate the ground displacements, cracking of structural or non-structural elements alike, tilting and distortions are likely to occur, leading to a loss of cosmetic, functional, durability or structural functionality aspects.

In the heavily urbanised coastal-deltaic plain of the Netherlands, (masonry) buildings often rest on heterogeneous soil that includes peaty, clayey and silty strata, which predisposes the occurrence of creep settlements over very long times.

Numerical simulations for settlement-induced damage

The measurements of full-scale structures are crucial to improve the existing relationships between ground movements and building damage (Son and Cording, 2005). However, the lack of detailed information of the exposed structure and subsurface limits the generalization of conclusions.
Numerical models provide a reliable alternative to evaluate the effect of variability of the employed parameters, representing different controlled variations (e.g. different settlement shapes).

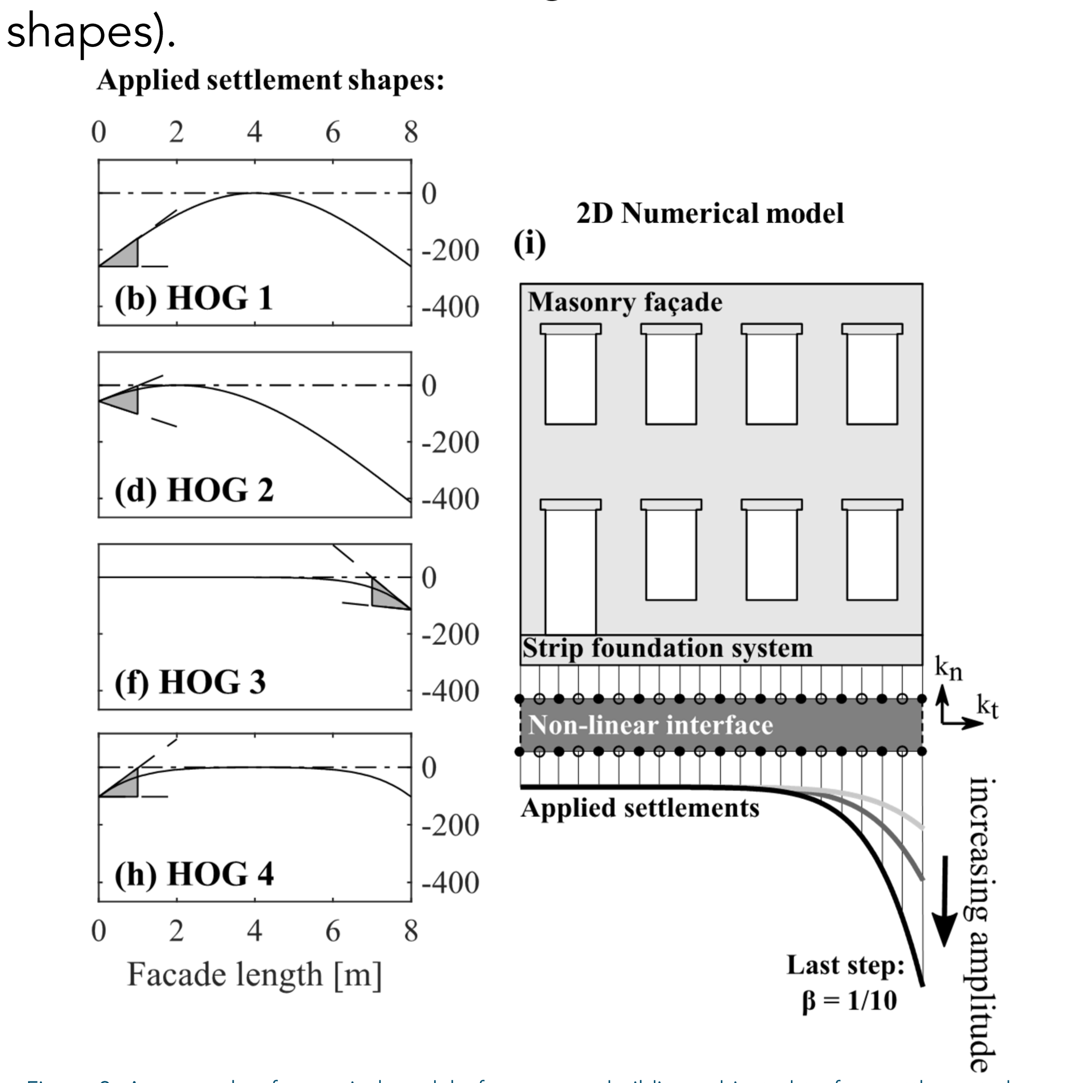

Figure 2. An example of numerical model of a masonry building subjected to four settlement shapes: HOG1, HOG2, HOG3, HOG4 from Fig. 2.

Methodology to characterize and quantify the damage

The results of the numerical analyses can be used to directly and objectively assess the extent of the induced damage in each wall of the building. The parameter Ψ in equation (1) proposed by Korswagen et al., 2019 is used to quantify the damage in the numerical models in one single scalar value:

$$\Psi = 2\, n_c^{\,0.15}\, \hat{c}_w^{\,0.3} \tag{1}$$

Where n_c is the number of cracks, $\hat{c}_w$ is the width-weighted and length averaged crack width (in mm).

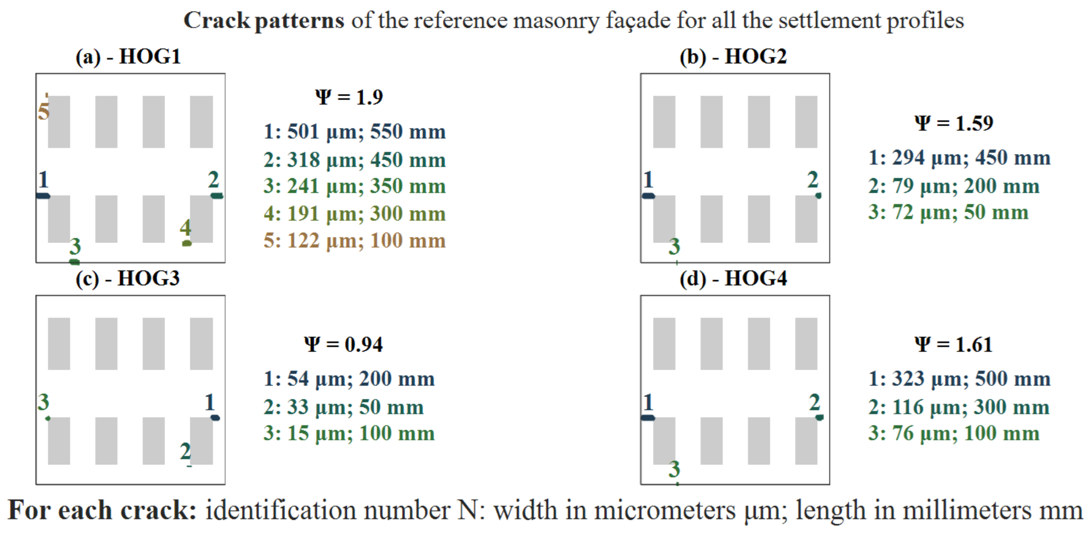

Figure 3. Crack patterns of the masonry façade for all the settlement profiles (HOG1 -4).

Numerical-based fragility functions

The results of the numerical simulations can be used to develop probabilistic relationships, namely fragility curves, that links the amount of settlement that affects a structure with the probability of a specific level of damage.

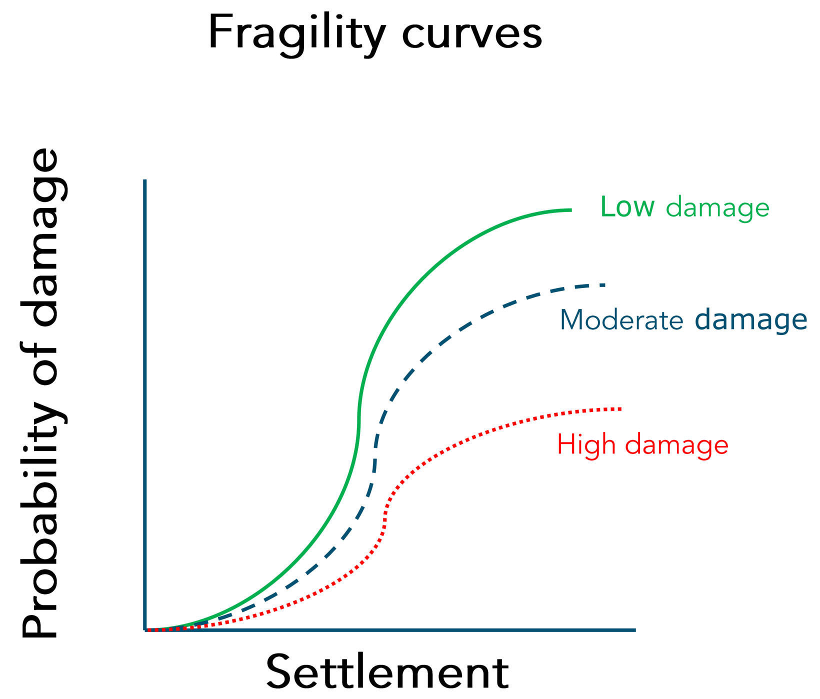

Figure 4. Schematic illustration of fragility functions

Recent publications

Journal articles:

- Prosperi, A., Korswagen, P. A., Korff, M., Schipper, R., & Rots, J. G. (2023a). Empirical fragility and ROC curves for masonry buildings subjected to settlements. Journal of Building Engineering, 106094.
- Prosperi, A., Longo, M., Korswagen, P. A., Korff, M., & Rots, J. G. (2023b). Sensitivity modelling with objective damage assessment of unreinforced masonry façades undergoing different subsidence settlement patterns. Engineering Structures, 286, 116113.
- Prosperi, A., Longo, M., Korswagen, P. A., Korff, M., & Rots, J. G. (2024). 2D and 3D Modelling Strategies to Reproduce the Response of Historical Masonry Buildings Subjected to Settlements. International Journal of Architectural Heritage, 1-17.

Conference contributions:

- Prosperi, A., Longo, M., Korswagen, P. A., Korff, M., & Rots, J. G. (2023c). Shape matters: Influence of varying settlement profiles due to multicausal subsidence when modelling damage in a masonry façade. In Tenth International Symposium on Land Subsidence 2023.
- Prosperi, A., Longo, M., Korswagen, P. A., Korff, M., & Rots, J. G. (2023d). Accurate and Efficient 2D Modelling of Historical Masonry Buildings Subjected to Settlements in Comparison to 3D Approaches. In International Conference on Structural Analysis of Historical Constructions (pp. 232-244). Cham: Springer Nature Switzerland.

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- Ferlisi, S., Nicodemo, G., Peduto, D., Negulescu, C., & Grandjean, G. (2020). Deterministic and probabilistic analyses of the 3D response of masonry buildings to imposed settlement troughs. Georisk: Assessment and Management of Risk for Engineered Systems and Geohazards, 14(4), 260-279.
- Saeidi, A., Deck, O., & Verdel, T. (2009). Development of building vulnerability functions in subsidence regions from empirical methods. Engineering Structures, 31(10), 2275-2286.
- Son M, Cording EJ. Estimation of building damage due to excavation-induced ground movements. Journal of Geotechnical and Geoenvironmental Engineering. 2005;131:162-77.
- Korswagen PA, Longo M, Meulman E, Rots JG. Crack initiation and propagation in unreinforced masonry specimens subjected to repeated in-plane loading during light damage. Bulletin of Earthquake Engineering. 2019;17:4651-87.
- DeJong M. Thematic Keynote: Settlement effects on masonry structures. Structural Analysis of Historical Constructions: Anamnesis, Diagnosis, Therapy, Controls: Proceedings of the 10th International Conference on Structural Analysis of Historical Constructions (SAHC, Leuven, Belgium, 13-15 September 2016): CRC Press; 2016. p. 449-56.

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